Improving Fuze Range Sensing in Small/Medium Caliber Munitions

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Range Sensing in Small/Medium Caliber Munitions: Technical Challenges/Barriers

- **Need very high accuracy:** air burst lethality for prone infantry is very sensitive to even small range errors. Many sources can each contribute significant error.
- **Severe design constraints:** small volume, low unit cost, and extreme ruggedness are required for small/medium caliber projectiles. This precludes many options (specifically, GPS)

This is a very tough problem!

Conventional Approach to Range Sensing Problem

- Fire control computer simulates nominal trajectory and passes target time/turns to projectile before firing
- Timer used to gauge when targeted time value has been attained in-flight

or

Turns counter used to gauge when targeted turns count value has been attained in-flight

Objectives for TPA "Fuze Range Sensing" Supported by ARL and ARDEC ALACV STO

- Investigate various concepts of range sensing for direct fire, air burst fuzing in (two) 40mm prototypes:
  - Accuracy of various existing concepts
  - Maturity/viability of hardware required for each concept
  - Size/power/weight/ruggedness/cost considerations
  - Development and performance prediction of new concepts
- Algorithm development (FY01)
- Detailed range sensor design and lab evaluation (FY02)
- High-G qualified prototype design to ARDEC for field tests (FY03)

ALACV 40mm RFI Fuze Technology Specs

- **Multifunction, modularly designed fuze**
- **Fuze technology must be adaptable to other caliber ranges**
- **Priority of functional modes:**
  - **Air burst, direct fire (ground target)**
    - **Target range: 0 to 3 km**
    - **Burst within +/- 5.0 m (Threshold) or +/- 3.0 m (Objective) of target range**
  - **Impact delay**
  - **Point detonate**
  - **Barrage mode “HOB” (desired)**
    - **Ranges of 4500 m to 8500 m**
    - **Burst at heights of between 3 to 5 m above surface**

ALACV RFI: Generic "Conventional" Response

- Air burst range sensing
  - Higher precision timer
  - Turns counter
  - Muzzle-exit-velocity-corrected time
  - Temperature insensitive propellant
- Barrage mode
  - Technical risk: energy storage requirements for > 5km
  - Requires HOB prox sensor (impractical at 40mm)
  - "String of pearls" if no HOB prox sensor

ARL Premises Concerning Conventional Approach

- **Shortcomings of conventional approaches**
  - **Too many error sources to deal with individually**
  - **Many error sources can <u>each</u> contribute significant range error**
  - **No one “silver bullet” sensor modality (eg. timer, turns counter)**
  - **Cannot handle multiple error sources**
  - **Little or no attempt at sensor fusion**
  - **Valuable sensor information is not utilized**
- **Sensor fusion makes sense:**
  - **Each sensor modality provides new information**
  - **1-D MEMS accelerometers add additional information when they become available**

Conventional approaches are inadequate to meet ALACV goals. An innovative generic approach is needed!

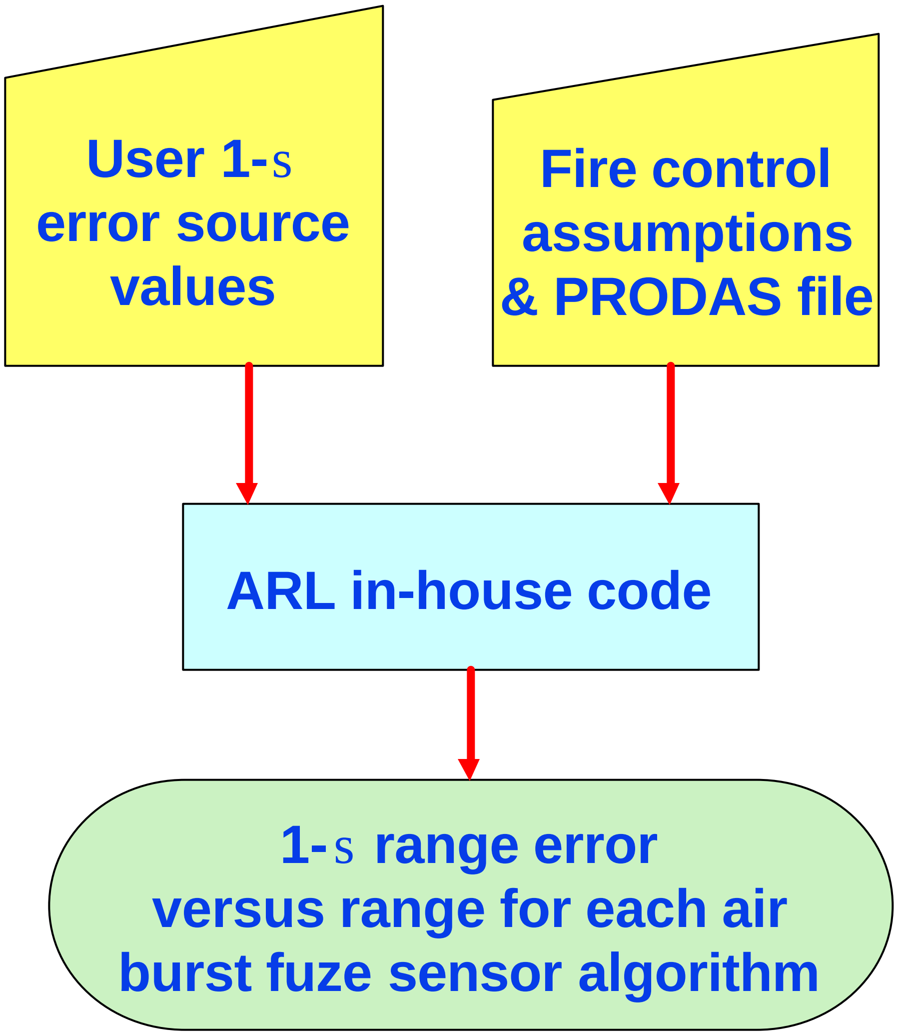
Summary: Conventional vs. ARL Approach to Range Sensing

"Conventional wisdom" : Evolutionary	ARL approach: Revolutionary
Methodologies • Time • Corrected Time (corrected for muzzle exit velocity) • Turns (insensitive to muzzle exit velocity) • Time/turns hybrid	**Methodology** Sensor Fusion: Time Turns Accelerometers Possibly others
• Deals with one error source at a time (muzzle exit velocity)	• Deals with all error sources simultaneously

ARL Modeling, Simulation, and Analysis

Developed new capability: Custom PRODAS module and Mathematica modules developed to allow:

- User-programmable fuze sensing algorithms in Mathematica
- Monte Carlo burst point error statistics
- Time, corrected time, turns count, 1D acceleration, and time-turns hybrid (built-in functions)
- Range-premature (and late HOB) ground impact bursts are accounted for

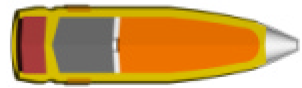


Initial and Nominal Error Source Data for Simulation

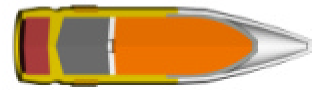
Initial conditions:
- **Target altitude = 0 m**
- **intended air burst altitude = 3.0 m**

Nominal values in PRODAS file:
- **V_0 = 1044m/s (40mm) & 805m/s (30mm)**
- **Standard met, etc.**

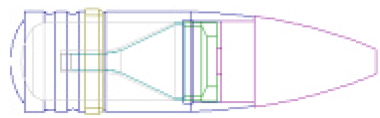
ALACV 40mm prototypes:



Concept 12



Concept 2SW



30mm 789

Time-turns hybrid: turns counting for supersonic, timing for subsonic

Muzzle velocity corrected time = (nominal muzzle vel/ actual muzzle vel) x nominal time to range

One-Sigma Error Sources (Arrow Tech default values)

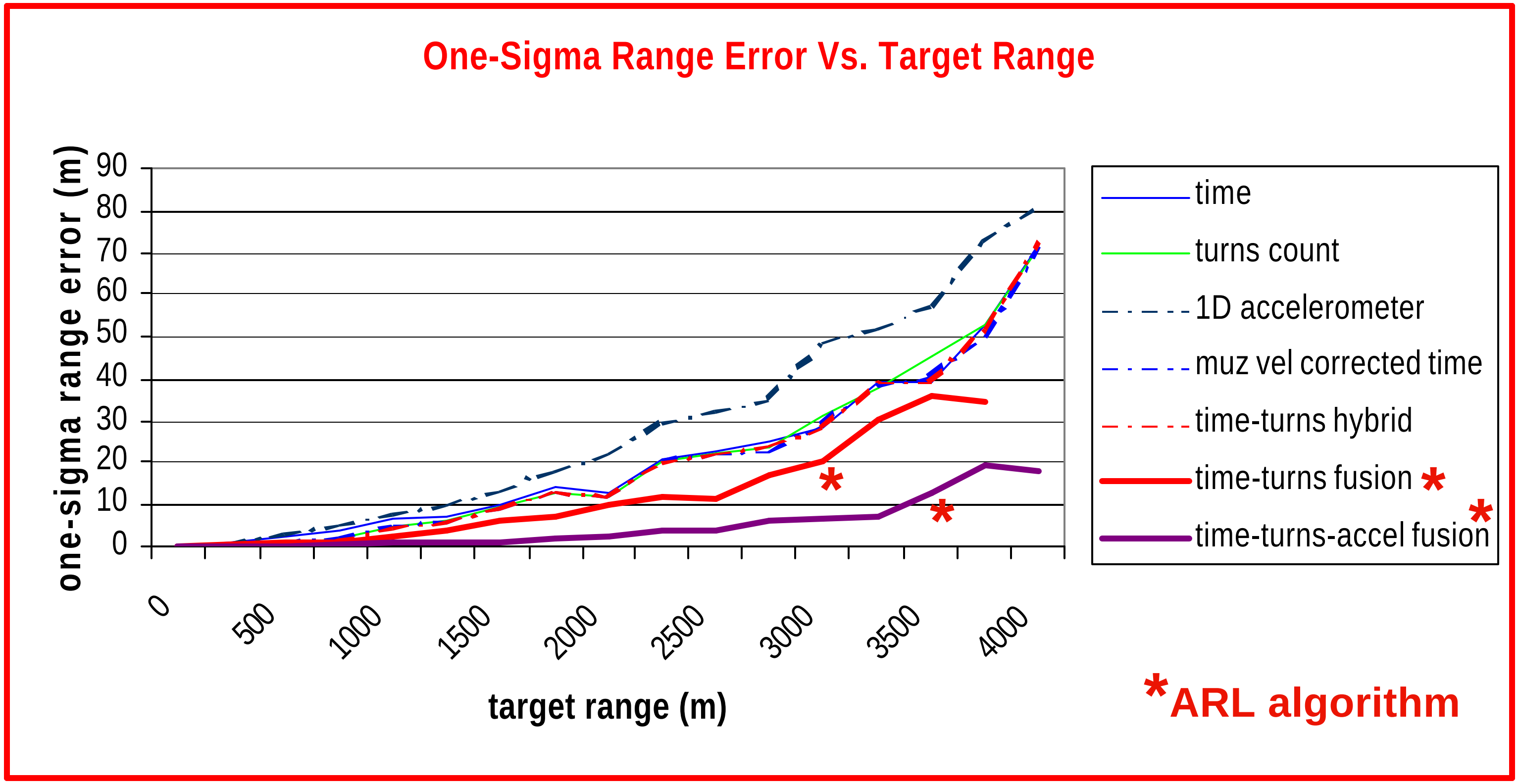
Occasion-to-occasion:

gun elevation	gun azimuth	gun twist	target range	muzzle velocity	ammo temp	velocity slope	Drag/Mass	lift	thrust	air temp	air pressure	wind (range & cross)
0.5 mils	0.5 mils	1.0 %	0.5 %	2.5 m/s	5.0 deg-C	0.25 m/s/deg-C	0.5 %	0.2 %	0.5 %	0.96 %	0.60 %	2.20 m/s
				lot-to-lot		LAT data (not one-sigma)	lot-to-lot			1/2 hour stale Met	1/2 hour stale Met	1/2 hour stale Met

Round-to-round:

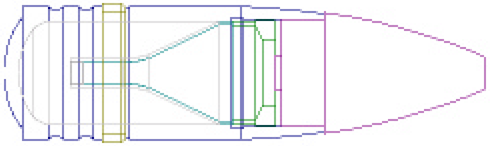
gun dyn elevation	gun dyn azimuth	prj jump elevation	prj jump azimuth	muzzle velocity	Drag/Mass	lift	spin decay	thrust	range wind	cross wind	time set	turns set	accel set
0.6 mils	0.6 mils	0.5 mils	0.5 mils	3.0 m/s	0.5 %	0.5 %	2.0 %	0.5 %	0.5 m/s	0.5 m/s	0.1 %	0.1 %	0.1 %
gun dynamics		proj. disp. (TID)		round-to-round	round-to-round								

30mm Range Sensing Simulation Results



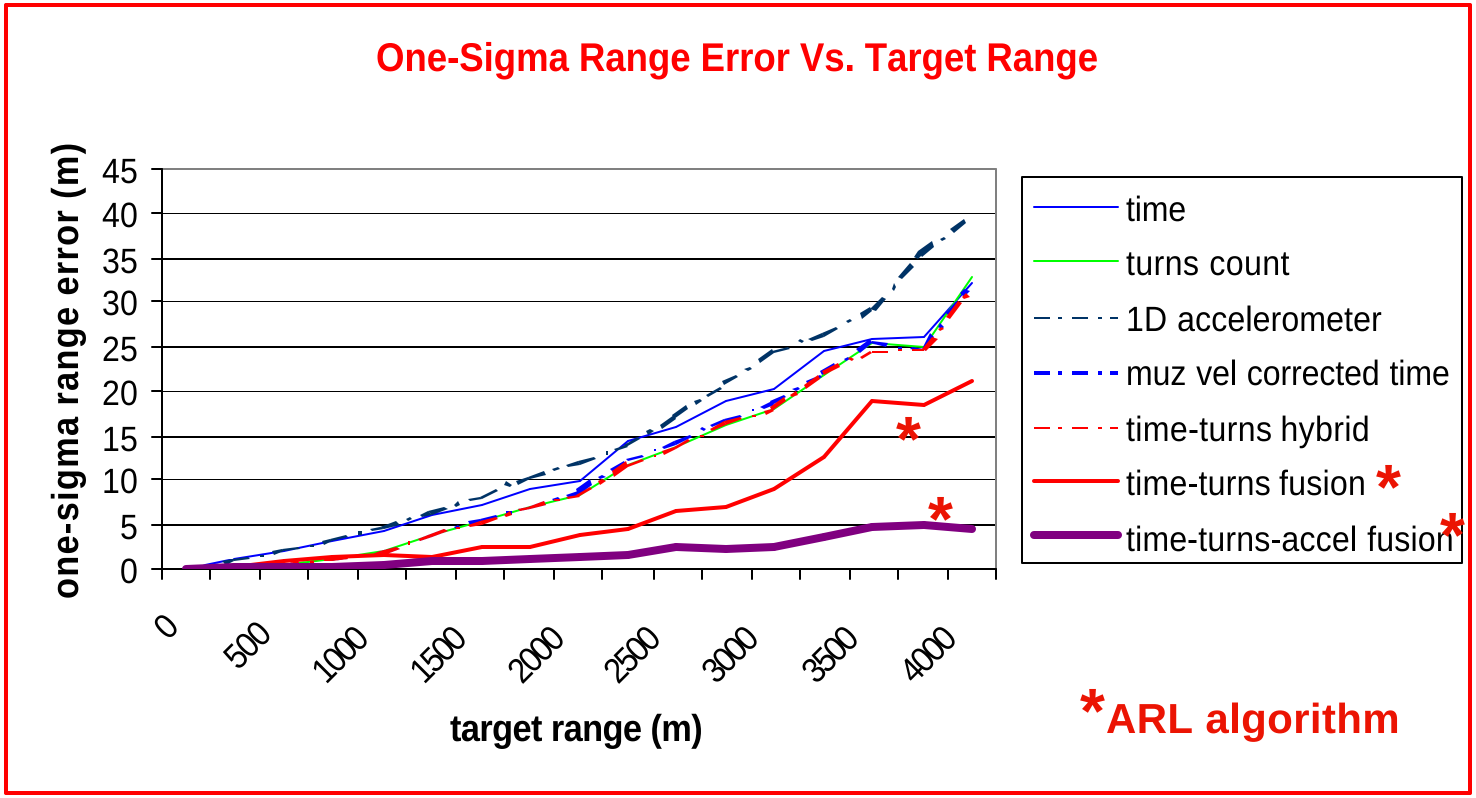
PRODAS MPM-4DOF 8,000 trajectories:

- **Simulations at 16 target ranges (every 250 m out to 4000**
- **50 occasions per target range value**
- **10 rounds per occasion**



30mm 789

ALACV 40mm Range Sensing Simulation Results



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Concept 2SW

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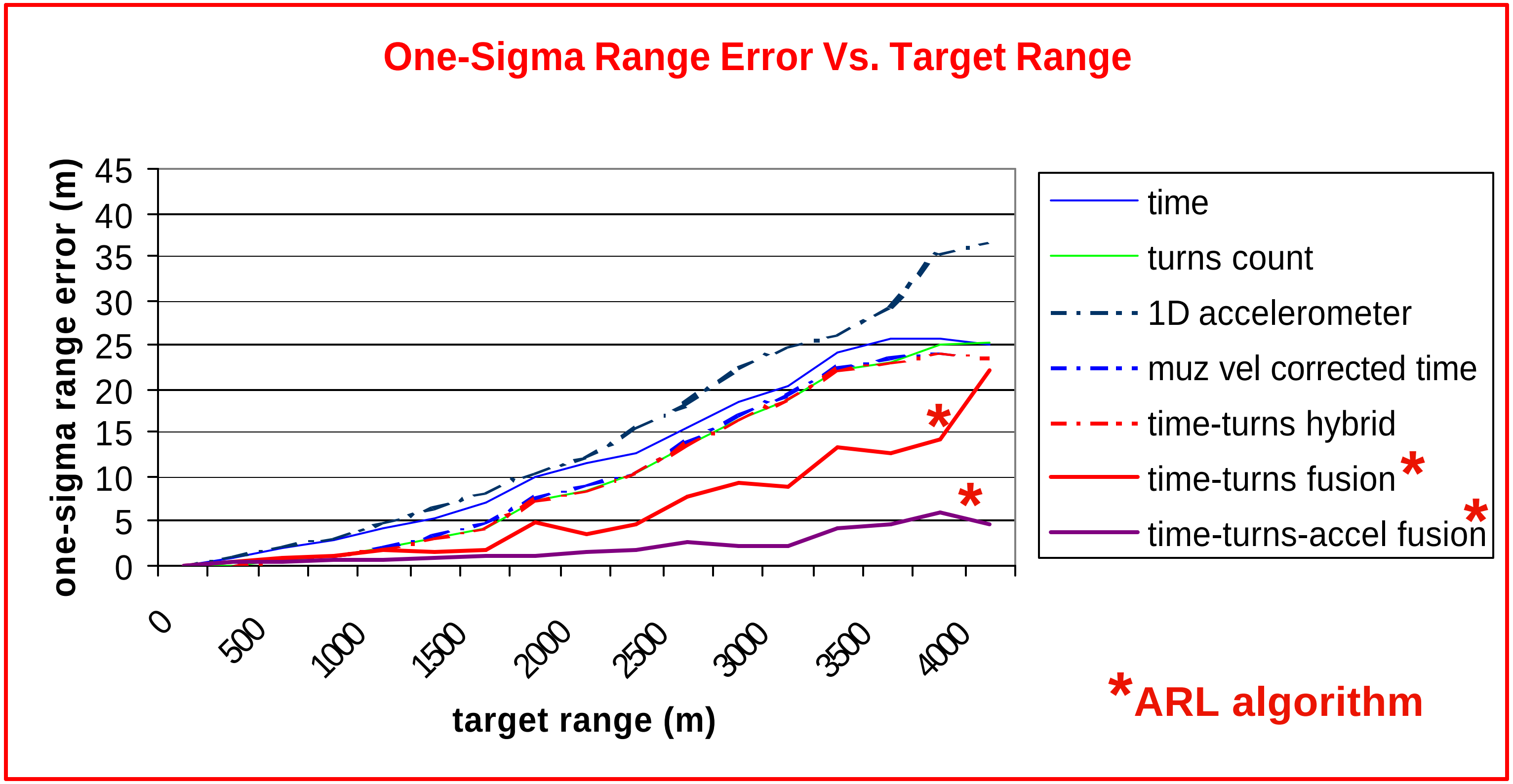

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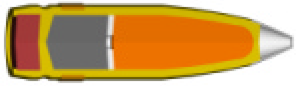
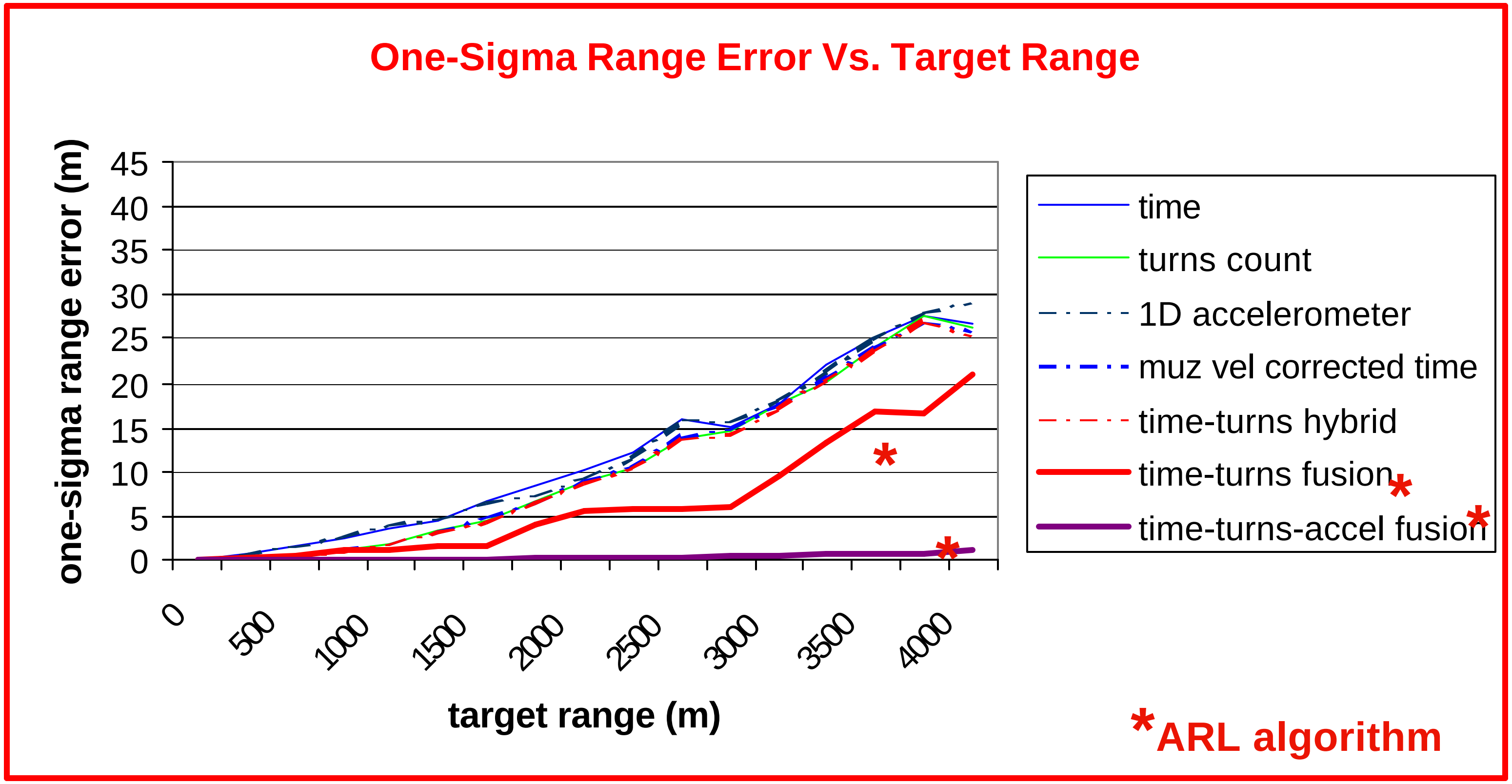


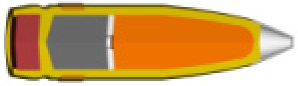
Concept 12

Perturbed Error Source One-Sigma Values



PRODAS MPM-4DOF
8,000 trajectories, etc.
(as in previous case)

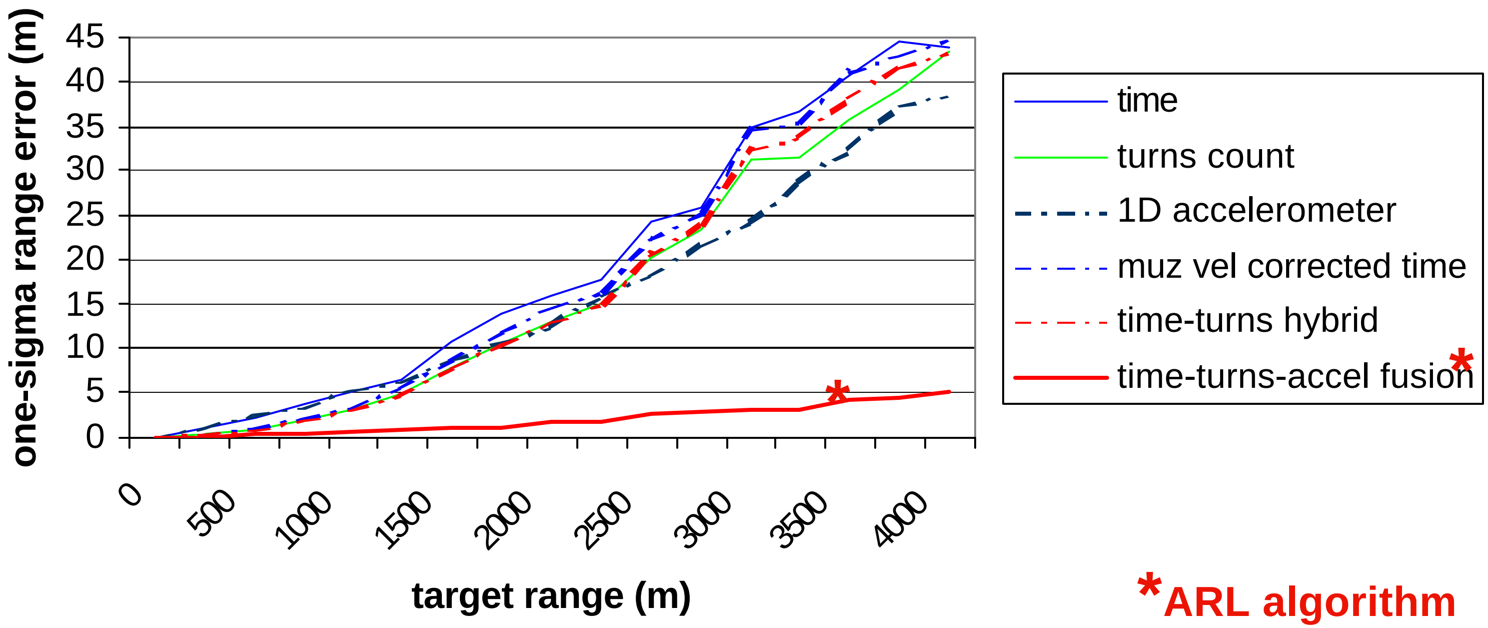
- **Round-round muzzle exit velocity one-σ error reduced from 3.0 to 1.5m/s**
- **Twist one-σ error reduced from 1% to 0.1%**



Concept 12

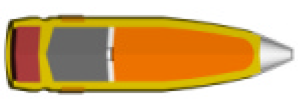
Perturbed Error Source One-Sigma Values

One S.D. Range Error vs. Target Range



- **Air temperature and pressure one-s error increased to 1.50%**
- **Range and cross wind one-s error increased to 3.35m/s**
- **Drag/Mass round-to-round one-s error increased to 0.75%**

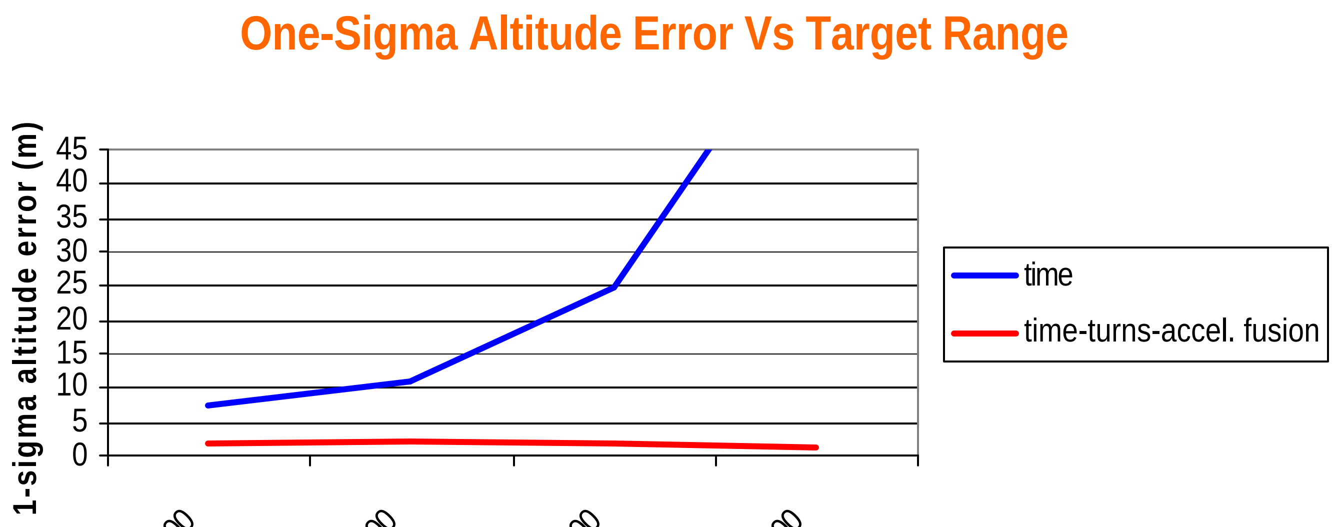
PRODAS MPM-4DOF
8,000 trajectories, etc.
(as in previous case)

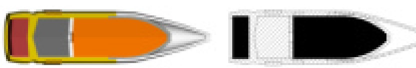


Concept 12

ALACV 40-mm HOB Sensing Simulation Results

Note: Assumes gun-rugged MEMS accelerometer technology (under development)



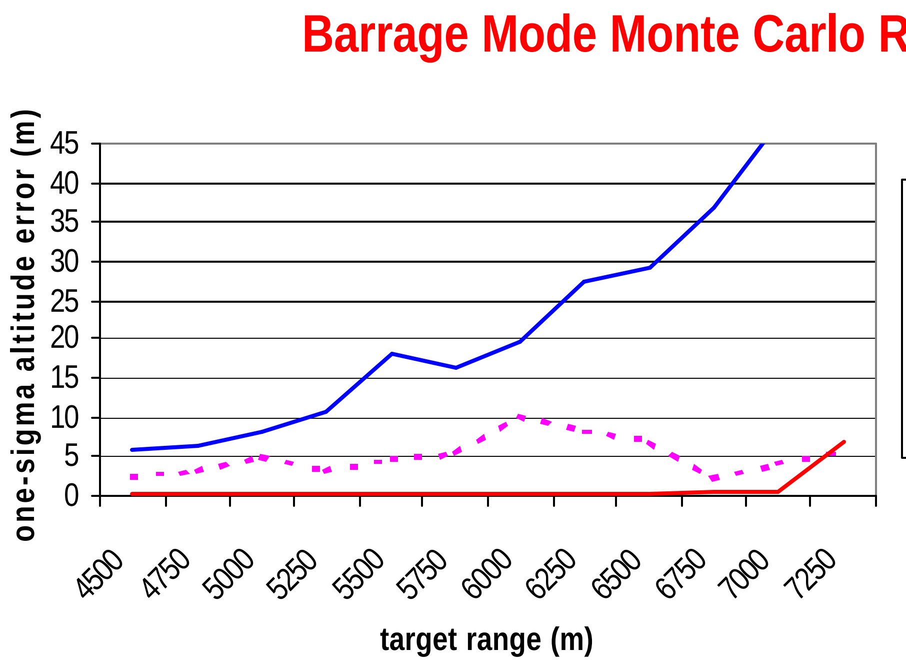


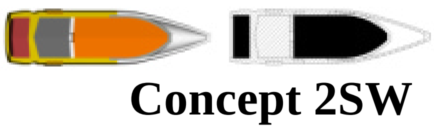
PRODAS MPM-4DOF: 2,000 trajectories:

- **Simulations at 4 target ranges: 4500 m, 5000 m, 6000 m, and 7000 m**
- **50 occasions per target range value**
- **10 rounds per occasion**

ALACV 40mm HOB Sensing Simulation Results

Assumes current GMR magnetometer technology





PRODAS MPM-4DOF: 6,000 trajectories:

- **50 occasions per target range value**
- **10 rounds per occasion**
- **Simulations at 12 target ranges: every 250 m from 4500 m to 7250 m (max projectile range=7367m)**

Fusion of multiple sensor data has potential to satisfy HOB accuracy goals without HOB prox sensors at little or no additional cost!

ALACV 40-mm Barrage Mode HOB Summary (Preliminary)

- Time/turns fusion: <10 m HOB error (1-sigma)
  - (+) Uses mature sensor technology
  - (–) Does not meet STO barrage mode goals
  - (+) Significant improvement in baseline performance
- Time/turns/accel fusion: <3 m HOB error
  - (++) Meets STO barrage mode (w/ range) goals at no extra cost
  - (++) Also could be used to meet PD and delay mode goals
  - (–) Requires gun-rugged accelerometer (emerging technology)
- Time/turns/orientation fusion: <1 m HOB error
  - (+) Meets STO barrage mode goals (almost meets range goals)
  - (+) Uses emerging (Harkins & Hepner, ARL-TR-2310) MAGSONDE technology
  - (–) Requires two magnetometers (or E-field sensors)

Time/turns/acceleration/orientation fusion: near-perfect?

ARL Approach Summary:

ARL approach is revolutionary:

- Only algorithm to meet (and exceed) STO goals
- Adaptable to barrage (HOB) application (indirect fire)
- First to address all error sources simultaneously
- Readily extendable to additional/improved sensors
- Can be optimized (results shown are not optimal)
- Readily extendable to other caliber rounds
- Inexpensive back up to GPS and /or HOB prox sensor (subject to jamming and/or clutter) in large caliber

The ARL approach represents a new paradigm in range sensing and possibly in indirect fire HOB sensing!

Potential Issues w.r.t. Implementing ARL Algorithm

- **FC-projectile data transfer time < dwell time associated with rate-of-fire**
- **On-board CPU/DSP computational speed**
- **Accessibility of round for setting**
- **Fire Control**
  - **Computational speed**
  - **Programming issues**
  - **Projectile interface**

Parameter Values Assumed for ARL Sensor Fusion Algorithm

Reported results are based upon following minimum values (red):

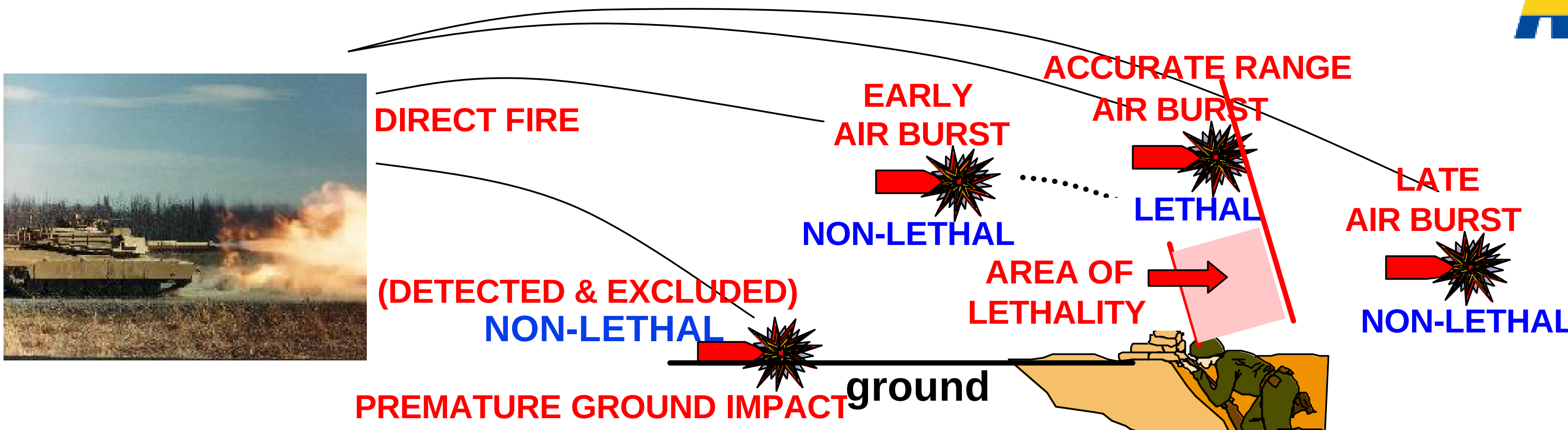
Projectile CPU speed	0.325 MFLOPS	Motorola DSP5685x: 120MHz, 1.8 V, < 50-120 mA $4 each
Program ROM	Estimated < 32 kB	
Program RAM	Estimated < 32 kB	
Data transfer from FC to projectile	2.6 kB/round	Demonstrated in OCSW (25 mm): 200 ms dwell time for 250 rounds/min

Algorithm performance will improve with time!

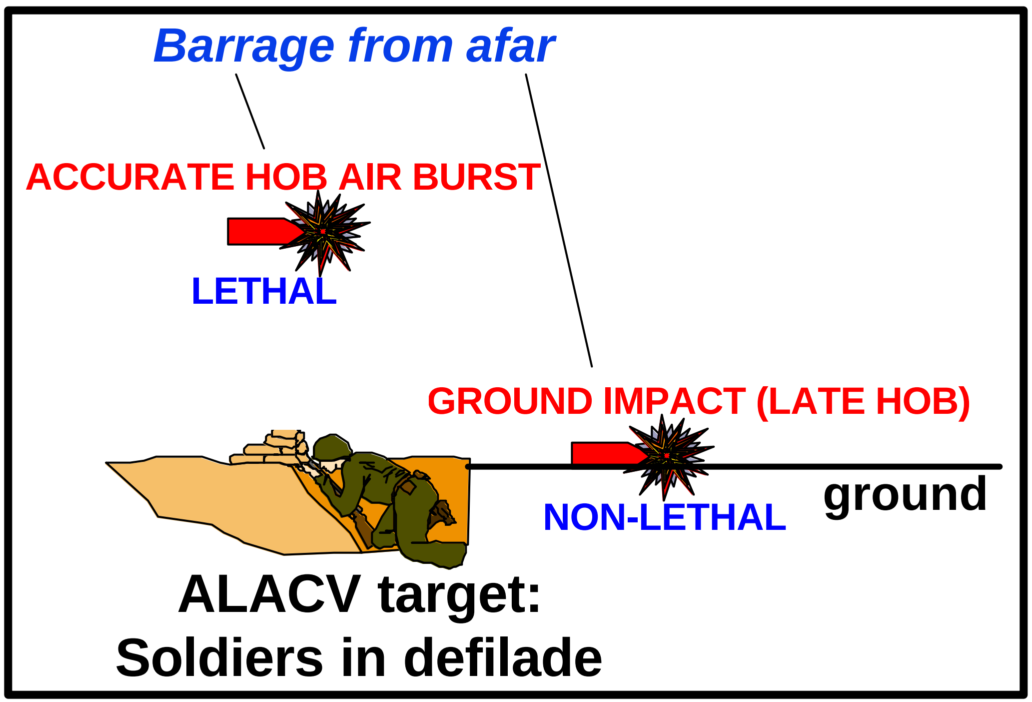
In a Nutshell….

- The ARL approach could revolutionize fuzing
  - Quantum improvement in range sensing accuracy
  - Also solves barrage mode requirements
- Applications to many munitions
- Would like to expand algorithm/simulation and method-optimization efforts started in FY01
- Need flight data to validate models/simulations

Air Burst Lethality



ALACV target:
Soldiers in defilade



Comparisons between results for each simulated range sensing method are made on <u>common basis of excluding bursts with NO POTENTIAL for lethality</u>